



Munich Personal RePEc Archive

# **Do Stronger Patents Stimulate or Stifle Innovation? The Crucial Role of Financial Development**

Chu, Angus C. and Cozzi, Guido and Pan, Shiyuan and  
Zhang, Mengbo

Fudan University, University of St. Gallen, Zhejiang University,  
University of California, Los Angeles

September 2016

Online at <https://mpra.ub.uni-muenchen.de/78988/>

MPRA Paper No. 78988, posted 07 May 2017 07:02 UTC

# Do Stronger Patents Stimulate or Stifle Innovation? The Crucial Role of Financial Development

Angus C. Chu      Guido Cozzi      Shiyuan Pan      Mengbo Zhang

April 20, 2017

## Abstract

This study explores the effects of patent protection in a distance-to-frontier R&D-based growth model with financial frictions. We find that whether stronger patent protection stimulates or stifles innovation depends on credit constraints faced by R&D entrepreneurs. When credit constraints are non-binding (binding), strengthening patent protection stimulates (stifles) R&D. The overall effect of patent protection on innovation follows an inverted-U pattern. An excessively high level of patent protection prevents a country from converging to the world technology frontier. A higher level of financial development influences credit constraints through two channels: decreasing the interest-rate spread and increasing the default cost. Through either channel, a higher level of financial development stimulates innovation, but the two channels of financial development interact with the effects of patent protection differently. Via the interest-spread (default-cost) channel, patent protection is more likely to have a negative (positive) effect on innovation under a higher level of financial development. We test these results using cross-country regressions and find that patent protection and financial development have a negative interaction effect on innovation.

*JEL classification:* O31, O34, E44

*Keywords:* Patent protection, credit constraints, economic growth, convergence

Chu: angusccc@gmail.com. China Center for Economic Studies, School of Economics, Fudan University, Shanghai, China. Cozzi: guido.cozzi@unisg.ch. Department of Economics, University of St. Gallen, St. Gallen, Switzerland. Pan: shiyuanpan@zju.edu.cn. School of Economics, Zhejiang University, Hangzhou, China. Zhang: mbzhang@ucla.edu. Department of Economics, University of California, Los Angeles, United States. The authors would like to thank Margaret Davenport for her excellent research assistance. The usual disclaimer applies.

# 1 Introduction

In this paper, we explore the effects of patent protection in a distance-to-frontier R&D-based growth model, in which a country invests in R&D to adopt technologies from the world technology frontier and may gradually converge to the technology frontier. A novelty of our growth-theoretic analysis of patent policy is that we consider financial frictions in the form of potentially binding credit constraints on R&D entrepreneurs. As in Aghion *et al.* (2005), due to moral hazard, R&D entrepreneurs may not be able to borrow as much as they want for their R&D investment. When these credit constraints are non-binding, we find that strengthening patent protection by increasing patent breadth leads to a larger amount of monopolistic profit, which stimulates R&D and technological progress. This positive *monopolistic-profit* effect captures the traditional view of patent protection. However, when the credit constraints are binding, we find that the monopolistic distortion arising from patent protection leads to more severe financial frictions, which stifle R&D and slow down technological progress. The intuition of this negative *financial distortionary* effect of patent protection can be explained as follows. Strengthening patent protection causes more severe monopolistic distortion, which in turn reduces aggregate income and tightens credit constraints faced by R&D entrepreneurs. As a result, the rates of innovation and economic growth decrease. This finding is consistent with recent studies that often find the presence of negative effects of patent protection on innovation.<sup>1</sup> Furthermore, we find that the positive monopolistic-profit effect of patent protection prevails when the level of patent protection is below a threshold value, whereas the negative financial distortionary effect of patent protection prevails when the level of patent protection is above the threshold. Therefore, the overall effect of patent protection on R&D and innovation follows an inverted-U pattern that is commonly found in empirical studies.<sup>2</sup> An excessively high level of patent protection even prevents a country from converging to the world technology frontier. In this case, the country's technology level relative to the world technology frontier converges to zero in the long run.

We consider the case in which a higher level of financial development influences credit constraints through two channels: increasing the default cost as in Aghion *et al.* (2005) and decreasing the interest-rate spread. Empirical studies, such as Lerner and Schoar (2005), Qian and Strahan (2007) and Liberti and Mian (2010), often find that financial development reduces interest rates, the contracting cost of financing and the collateral spread of capital. We find that by decreasing the interest-rate spread or increasing the default cost, a higher level of financial development stimulates innovation. Intuitively, by decreasing the interest-rate spread, the interest rate becomes lower, which in turn increases the present value of future monopolistic profits and the value of inventions. By increasing the default cost, R&D entrepreneurs are less likely to default, and hence, banks are more willing to lend to entrepreneurs for their R&D investment.

Interestingly, the two channels of financial development interact with the effects of patent protection differently. We find that via the interest-spread (default-cost) channel, patent protection is more likely to have a negative (positive) effect on innovation under a higher level of financial development. The intuition of these results can be explained as follows. When the interest-rate spread decreases, the present value of future profits and the value of inventions increase. Consequently, entrepreneurs are incentivized to borrow more funding for R&D, rendering the

---

<sup>1</sup>See for example Jaffe and Lerner (2004), Bessen and Meurer (2008) and Boldrin and Levine (2008).

<sup>2</sup>See for example Qian (2007) and Lerner (2009).

credit constraints more likely to be binding in which case patent protection has a negative effect on innovation. When the default cost increases, banks become more willing to lend to R&D entrepreneurs, rendering the credit constraints less likely to be binding in which case patent protection has a positive effect on innovation.

We test the above theoretical implications using cross-country regressions. We find that patent protection and financial development have direct positive effects on economic growth. This finding is consistent with Ang (2010, 2011) who also empirically explore the effects of both patent protection and financial development on R&D activity. We complement the analysis in Ang (2010, 2011) by considering the interaction effect of patent protection and financial development on economic growth. In summary, we find that patent protection and financial development have a negative interaction effect on innovation, which is consistent with the interest-spread channel through which patent protection is more likely to have a negative effect on innovation under a higher level of financial development. Therefore, to capture the complete effects of patent policy on economic growth, it is useful to take into consideration the interaction between patent protection and financial development.

This study relates to the literature on patent policy. In this literature, Nordhaus (1969) provides the seminal study in which he shows that increasing patent length causes a positive effect on innovation and a negative static distortionary effect on welfare. While Nordhaus (1969) focuses on a partial-equilibrium framework, we consider a dynamic general-equilibrium (DGE) model in which the monopolistic distortion caused by patent protection interacts with financial frictions to affect credit constraints and stifle innovation. Subsequent studies in this literature, such as Gilbert and Shapiro (1990) and Klemperer (1990), explore patent breadth in addition to patent length. Scotchmer (2004) provides a comprehensive review of this patent-design literature. Our study instead explores the effects of patent policy in a DGE model in which the financial distortionary effect of patent policy arises through a general-equilibrium channel. Therefore, this study relates more closely to the macroeconomic literature on patent policy and economic growth based on DGE models.

The seminal DGE analysis of patent policy is Judd (1985), who finds that an infinite patent length maximizes innovation and eliminates the relative-price distortion because all industries charge the same markup. Our model features an infinite patent length under which the relative-price distortion is absent as in Judd (1985). However, we show that patent breadth interacts with a financial distortion that affects credit constraints and R&D. Subsequent studies in this literature explore patent breadth as an alternative patent-policy instrument; see for example, Li (2001), Goh and Olivier (2002) and Iwaisako and Futagami (2013).<sup>3</sup> Some of these studies also find that strengthening patent protection has an inverted-U effect on innovation and growth. Our study differs from these previous studies by exploring the effects of patent protection in the presence of financial frictions and in a distance-to-frontier R&D-based growth model that enables us to explore the technology convergence of countries. Chu, Cozzi and Galli (2014) also analyze the effects of patent protection in a distance-to-frontier model and show that the innovation-maximizing level of patent protection depends on the income level of a country. However, the abovementioned studies

---

<sup>3</sup>For other patent-policy instruments, see O'Donoghue and Zweimuller (2004) and Kiedaisch (2015) on patentability requirement, Furukawa (2007) and Horii and Iwaisako (2007) on protection against imitation, Dinopoulos and Syropoulos (2007) and Davis and Sener (2012) on rent protection activities, and Chu (2009), Chu, Cozzi and Galli (2012), Chu and Pan (2013) and Cozzi and Galli (2014) on blocking patents. These studies neither consider financial frictions nor the distance-to-frontier approach.

neither feature financial frictions nor consider the interaction between patent protection and credit constraints, which are the novel contributions of this study.

The rest of this paper is organized as follows. Section 2 describes the model. Section 3 presents the theoretical results. Section 4 discusses the regression results. The final section concludes.

## 2 An R&D-based growth model with credit frictions

In this section, we consider a distance-to-frontier R&D-based growth model with financial frictions based on the seminal work of Aghion *et al.* (2005) and Acemoglu *et al.* (2006). We extend their model by allowing for variable patent breadth, the value of inventions being dependent on multiple periods of profits and an interest-rate spread that affects the present value of future profits. We consider a discrete-time model and use the model to explore the interaction effects of patent protection and credit constraints on the technology convergence of countries.

### 2.1 Households and workers/entrepreneurs

There is a continuum of countries, indexed by a superscript  $i$ , that are behind the world technology frontier.<sup>4</sup> For simplicity, we follow previous studies to assume that countries do not exchange goods or factors but are subject to international technology spillovers from the frontier. There is a unit continuum of infinitely-lived households in each country. These households own intangible capital (in the form of patents that generate monopolistic profits) and consume final goods (numeraire). The lifetime utility function of the representative household in country  $i$  is given by

$$U^i = \sum_{t=0}^{\infty} \frac{C_t^i}{(1+\rho)^t},$$

where the parameter  $\rho > 0$  is the subjective discount rate and  $C_t^i$  is consumption of the representative household in country  $i$  at time  $t$ . The asset-accumulation equation is  $A_{t+1}^i = (1+r_t^i)A_t^i - C_t^i$ . From standard dynamic optimization, the linear utility function implies that in equilibrium the real interest rate is equal to the discount rate, such that  $r_t^i = \rho$ .

In addition to the infinitely-lived households in the economy, we follow previous studies to assume the presence of overlapping generations of workers/entrepreneurs in each period to create a need for the entrepreneurs to borrow funding for R&D. At the beginning of each period  $t$ ,  $L$  workers enter the economy, and they work to earn wage  $W_t^i$ . At the end of the period, each worker becomes an entrepreneur and devotes part of her wage income  $\kappa^i W_t^i$  to R&D, where  $\kappa^i \in (0, 1)$ .<sup>5</sup> At the beginning of the next period, those entrepreneurs who have succeeded in their R&D projects sell their inventions to households and use the proceeds for consumption. Without loss of generality, we normalize  $L$  to unity. A worker who enters the economy in period  $t$  has the utility function  $u_t^i = y_t^i + E_t[o_{t+1}^i]/(1+\rho)$ , where  $y_t^i$  denotes consumption when young and  $E_t[o_{t+1}^i]$  denotes expected consumption when old. If the amount of her R&D spending  $Z_t^i$  is

<sup>4</sup>In this study, we do not model the behavior of the technology frontier and simply take it as given.

<sup>5</sup>Here we assume that the entrepreneur may not be able to devote her entire wage income to R&D. Our results also hold when  $\kappa^i = 1$ .

less than  $\kappa^i W_t^i$ , then a worker/entrepreneur simply consumes  $W_t^i - Z_t^i$  in period  $t$  or saves part of it subject to the market interest rate  $r_t^i$ . However, if  $Z_t^i > \kappa^i W_t^i$ , then the worker/entrepreneur would need to apply for a loan subject to credit constraints, which will be described in details in Section 2.7.

## 2.2 Final goods

The final goods sector is perfectly competitive. Firms in this sector employ workers and a continuum of differentiated intermediate goods  $v \in [0, N_t^i]$  to produce final goods using the following production function:

$$Y_t^i = (L_t^i)^{1-\alpha} \int_0^{N_t^i} [x_t^i(v)]^\alpha dv, \quad (1)$$

where the parameter  $\alpha \in (0, 1)$  determines labor intensity  $1 - \alpha$  in production.  $L_t^i$  is labor input.  $x_t^i(v)$  is the amount of intermediate goods  $v \in [0, N_t^i]$ , and  $N_t^i$  is the number of available intermediate goods in country  $i$  at time  $t$ . Competitive firms take the prices of final goods and factor inputs as given to maximize profit. The conditional labor demand function is given by  $W_t^i = (1 - \alpha)Y_t^i/L_t^i$ , where  $L_t^i = L = 1$  from the market-clearing condition. The conditional demand function for intermediate goods is given by

$$x_t^i(v) = \left[ \frac{\alpha}{p_t^i(v)} \right]^{1/(1-\alpha)}, \quad (2)$$

where  $p_t^i(v)$  is the price of intermediate goods  $v$  in country  $i$ .

## 2.3 Intermediate goods

Each differentiated intermediate good  $v$  is produced by a firm that owns the patent of the product and has market power, which is determined by the level of patent protection to be explained below. In industry  $v$ , the firm produces  $x_t^i(v)$  units of intermediate goods using  $x_t^i(v)$  units of final goods as inputs. Therefore, the profit function of the firm in industry  $v$  is

$$\Pi_t^i(v) = p_t^i(v) x_t^i(v) - x_t^i(v) = [p_t^i(v) - 1] \left[ \frac{\alpha}{p_t^i(v)} \right]^{1/(1-\alpha)}, \quad (3)$$

where the second equality follows from (2). Using (3), one can derive the profit-maximizing price  $p_t^i(v)$  given by  $1/\alpha$ . To capture the effects of patent protection, we follow Goh and Olivier (2002) to model patent breadth  $\beta^i \in (1, 1/\alpha)$  as a policy variable.<sup>6</sup> In this case,

$$p_t^i(v) = \beta^i. \quad (4)$$

---

<sup>6</sup>The idea is that the unit cost for other firms to produce an identical product is  $\beta^i$ , which is increasing in the level of patent protection. Therefore, stronger patent protection allows the producer who owns the patent to charge a higher markup; see also Li (2001) and Iwaisako and Futagami (2013) for a similar formulation. This formulation captures Gilbert and Shapiro's (1990) seminal insight on "breadth as the ability of the patentee to raise price".

Combining (3) and (4), we obtain the amount of profit as a function of patent breadth given by

$$\Pi_t^i(v) = (\beta^i - 1) \left( \frac{\alpha}{\beta^i} \right)^{1/(1-\alpha)} \equiv \pi(\beta^i), \quad (5)$$

which is increasing in  $\beta^i$  for  $\beta^i \leq 1/\alpha$ .

## 2.4 Aggregate production function

Substituting (2) and (4) into (1) yields

$$Y_t^i = \left( \frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} N_t^i. \quad (6)$$

Equation (6) shows that the growth rate of  $Y_t^i$  is determined by the growth rate of  $N_t^i$  and that the level of  $Y_t^i$  is decreasing in patent breadth  $\beta^i$ , which captures the effect of markup distortion on the level of output. In other words, by increasing the price of intermediate goods, a larger markup leads to less intermediate goods being produced and also less final goods being produced.<sup>7</sup> In the presence of credit constraints, patent protection would then generate a negative effect on R&D as a result of this markup distortion as we will show later.

## 2.5 R&D and the value of patents

In each country, there is an R&D sector. In each period  $t$ , workers/entrepreneurs devote final goods to R&D at the end of the period to invent new intermediate goods that will be produced in the next period. To ensure balanced growth, we assume that each entrepreneur spreads her R&D spending  $Z_t^i$  over  $N_t^i$  R&D projects.<sup>8</sup> Therefore, the amount of final goods that an entrepreneur devotes to each of her R&D projects is  $Z_t^i/N_t^i$ , and the probability of her R&D projects being successful is  $P_t^i = \min\{Z_t^i/(N_t^i\eta_t^i), 1\}$ ,<sup>9</sup> where  $1/\eta_t^i$  captures the productivity of R&D in country  $i$ .

We follow Acemoglu (2009, chapter 18) to assume that  $\eta_t^i$  is an increasing function in  $N_t^i/N_t$ , where  $N_t$  is the level of technology at the world technology frontier.  $N_t$  grows at a constant rate  $\bar{g} > 0$ , which is taken as given by other countries. Let's define country  $i$ 's relative technology level to the frontier as  $\mu_t^i \equiv N_t^i/N_t \in (0, 1)$ , which is an inverse measure of the country's distance to the world technology frontier. We adopt the following specification for  $\eta_t^i$ :

$$\eta_t^i = [\gamma(\mu_t^i)^\phi + \underline{\eta}] \left( \frac{Z_t^i}{N_t^i} \right)^\theta, \quad (7)$$

---

<sup>7</sup>If we follow Romer (1990) to assume that intermediate goods are produced from capital, instead of final goods, this markup distortion would still exist because the presence of markup and profits lowers capital income and reduces capital accumulation. However, allowing for capital accumulation would complicate the transition dynamics substantially.

<sup>8</sup>To ensure the innovation probability  $P_t^i \leq 1$  in the presence of growth in  $Z_t^i$ , we only need to assume that entrepreneurs spread their R&D spending  $Z_t^i$  over  $\varsigma N_t^i$  R&D projects, where  $\varsigma > 0$ . Without loss of generality, we set  $\varsigma = 1$ .

<sup>9</sup>For simplicity, we assume that an entrepreneur's R&D projects either all succeed or all fail.

where the parameters  $\{\gamma, \underline{\eta}\} > 0$  and  $\{\theta, \phi\} \in (0, 1)$  are common across countries. This specification features the catching-up effect under which a less developed country that has a smaller  $\mu_t^i$  is able to grow faster by absorbing more world technologies. The term  $(Z_t^i/N_t^i)^\theta$  captures an intratemporal duplication externality of R&D as in Jones and Williams (2000). Given the unit continuum of R&D entrepreneurs and the independence of R&D projects (across entrepreneurs), the law of large numbers applies, so that the accumulation of inventions at the aggregate level follows a deterministic process given by

$$\Delta N_t^i \equiv N_{t+1}^i - N_t^i = \frac{Z_t^i}{\eta_t^i} = \frac{N_t^i}{\gamma(\mu_t^i)^\phi + \underline{\eta}} \left( \frac{Z_t^i}{N_t^i} \right)^{1-\theta}, \quad (8)$$

where  $Z_t^i/\eta_t^i = N_t^i Z_t^i / (N_t^i \eta_t^i)$  is the number of successful R&D projects in period  $t$ .

Each R&D project has a probability  $P_t^i$  to give rise to a new variety of intermediate goods. When a new variety is successfully invented at the end of period  $t$ , production of the intermediate goods begins in period  $t + 1$ . We denote the value of an invention created in period  $t$  as  $V_t^i(v)$ . Here we assume that the discount rate for future profits is given by  $r^i + \epsilon^i = \rho + \epsilon^i$ , where  $\epsilon^i \geq 0$  denotes an exogenous interest-rate spread in country  $i$ . For example, Lerner and Schoar (2005), Qian and Strahan (2007) and Liberti and Mian (2010) find that financial development reduces interest rates, the contracting cost of financing and the collateral spread of capital. Here we use  $\epsilon^i$  to capture these financial frictions in a simple way.

Under the assumption above,  $V_t^i(v)$  can be expressed as

$$V_t^i(v) = \sum_{s=t}^{\infty} \frac{\Pi_{s+1}^i(v)}{(1 + r^i + \epsilon^i)^{s+1-t}} = \frac{\pi(\beta^i)}{\rho + \epsilon^i}, \quad (9)$$

which is increasing in patent breadth  $\beta^i$  and decreasing in  $\epsilon^i$ . The positive effect of  $\beta^i$  captures the positive effect of patent protection on the value of inventions. In a country that is more financially developed, there are less financial frictions, which in turn reduce the interest-rate spread  $\epsilon^i$  and increase the value of inventions. Finally, we make the following parameter restriction, which guarantees that  $P_t^i \in (0, 1)$  and  $\mu_t^i \in (0, 1)$ .

**Assumption 1**  $(\bar{g}^\theta \underline{\eta})^{1/(1-\theta)} < \pi(\beta^i) / (\rho + \epsilon^i) < \min\{\underline{\eta}^{1/(1-\theta)}, [\bar{g}^\theta(\gamma + \underline{\eta})]^{1/(1-\theta)}\}$ .<sup>10</sup>

## 2.6 Equilibrium without credit constraints

In this section, we explore the equilibrium level of R&D in the absence of credit constraints. The zero-expected-profit condition of R&D is given by  $P_t^i V_t^i = Z_t^i / N_t^i$ , which can be expressed as

$$V_t^i = \eta_t^i \Leftrightarrow \frac{\pi(\beta^i)}{\rho + \epsilon^i} = [\gamma(\mu_t^i)^\phi + \underline{\eta}] \left( \frac{Z_t^i}{N_t^i} \right)^\theta. \quad (10)$$

---

<sup>10</sup>The assumption  $\pi(\beta^i) / (\rho + \epsilon^i) < \underline{\eta}^{1/(1-\theta)}$  ensures  $P_t^i < 1$  for  $\mu_t^i \in (0, 1)$ . Derivations available upon request.



Therefore, the level of R&D in any period  $t$  is given by

$$Z_t^i = \left[ \frac{\pi(\beta^i)/(\rho + \epsilon^i)}{\gamma(\mu_t^i)^\phi + \underline{\eta}} \right]^{1/\theta} N_t^i, \quad (11)$$

which is increasing in  $\beta^i$  for a given level of relative technology  $\mu_t^i$ . The growth rate of technology is given by

$$g_t^i \equiv \frac{\Delta N_t^i}{N_t^i} = \frac{1}{\gamma(\mu_t^i)^\phi + \underline{\eta}} \left( \frac{Z_t^i}{N_t^i} \right)^{1-\theta} = \frac{1}{[\gamma(\mu_t^i)^\phi + \underline{\eta}]^{1/\theta}} \left[ \frac{\pi(\beta^i)}{\rho + \epsilon^i} \right]^{(1-\theta)/\theta}, \quad (12)$$

which is also increasing in patent breadth  $\beta^i$ , for a given  $\mu_t^i$ , capturing the positive *monopolistic profit* effect of patent protection on innovation. Furthermore, a higher level of financial development in the form of a decrease in the interest-rate spread  $\epsilon^i$  increases the growth rate of technology. We summarize these results in Proposition 1.

**Proposition 1** *In the absence of credit constraints, stronger patent protection leads to a higher growth rate of technology. A higher level of financial development in the form of a decrease in the interest-rate spread also leads to a higher growth rate of technology.*

**Proof.** Proven in text. ■

In the long run,  $\mu_t^i$  converges to a steady state, in which  $N_t^i$  grows at the same rate as  $N_t$ .<sup>11</sup> Setting  $g_t^i$  to the world technology growth rate  $\bar{g}$  in (12) yields the steady-state level of relative technology  $\mu_t^i$  given by

$$\mu^i = \frac{1}{\gamma^{1/\phi}} \left\{ \frac{1}{\bar{g}^\theta} \left[ \frac{\pi(\beta^i)}{\rho + \epsilon^i} \right]^{(1-\theta)} - \underline{\eta} \right\}^{1/\phi} \equiv \mu_1(\beta_+^i, \epsilon_-^i), \quad (13)$$

which is increasing in the level of patent breadth  $\beta^i$  and decreasing in the interest-rate spread  $\epsilon^i$ . Note that Assumption 1 ensures  $\mu_1 \in (0, 1)$  in the steady-state equilibrium. The balanced-growth level of R&D is given by

$$Z_t^i = \pi(\beta^i) \frac{\bar{g}}{\rho + \epsilon^i} N_t^i, \quad (14)$$

which is increasing in patent breadth  $\beta^i$  and decreasing in the interest-rate spread  $\epsilon^i$ . In other words, a decrease in the interest-rate spread  $\epsilon^i$  causes the entrepreneurs to want to do more R&D.

---

<sup>11</sup>We show the stability of this steady state in Section 2.8.

## 2.7 Equilibrium with credit constraints

Before the end of a period, each entrepreneur devotes her wage income  $\kappa^i W_t^i$  to  $N_t^i$  R&D projects without borrowing. If the R&D spending  $Z_t^i$  exceeds her wage income  $\kappa^i W_t^i$ , then she would have to borrow  $D_t^i = Z_t^i - \kappa^i W_t^i$  from a bank to finance her R&D projects. If her R&D projects succeed, she repays the loan plus an interest payment equal to  $(1 + R_{t+1}^i)D_t^i$  at the end of the period. If her R&D projects fail, she becomes bankrupt and repays nothing to the bank. Therefore, if the entrepreneur truthfully reveals the outcome of her R&D projects, the expected payment received by the bank is  $P_t^i(1 + R_{t+1}^i)D_t^i + (1 - P_t^i)0$ . When banks make zero expected profit, we have  $P_t^i(1 + R_{t+1}^i)D_t^i = D_t^i$ , which implies  $P_t^i(1 + R_{t+1}^i) = 1$ .

What makes it difficult to borrow is that an entrepreneur may want to default even when her projects are successful. We follow Aghion *et al.* (2005) to assume that banks do not observe the outcome of R&D projects, and hence, the problem of moral hazard arises. Specifically, by paying a default cost  $h^i Z_t^i$  where  $h^i \in (0, 1)$ , an entrepreneur can hide the outcome of her projects and avoid repaying the loan. The cost parameter  $h^i$  is an indicator of banks' effectiveness in securing repayment and partly measures the level of financial development in the country. In case an entrepreneur decides to default, the entrepreneur must incur the default cost before observing the outcome of her R&D projects. Therefore, entrepreneurs would not default if and only if the following incentive-compatibility (IC) constraint holds:

$$h^i Z_t^i \geq P_t^i(1 + R_{t+1}^i)D_t^i = D_t^i, \quad (15)$$

where  $D_t^i = Z_t^i - \kappa^i W_t^i = Z_t^i - \kappa^i(1 - \alpha)Y_t^i$ . Substituting this condition into (15) yields

$$Z_t^i \leq \frac{\kappa^i(1 - \alpha)Y_t^i}{1 - h^i} = \frac{\kappa^i(1 - \alpha)}{1 - h^i} \left( \frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} N_t^i, \quad (16)$$

where the last equality uses (6). We refer to this IC constraint as a credit constraint, which becomes tighter as patent breadth  $\beta^i$  increases capturing an interaction between the monopolistic distortion of patent protection and the financial distortion of the credit constraint. The intuition can be explained as follows. When patent breadth  $\beta^i$  increases, aggregate income  $Y_t^i$  decreases due to the markup distortion. As a result, a larger  $\beta^i$  reduces the income of entrepreneurs and their ability to borrow. This effect exists so long as entrepreneurs' ability to borrow is affected by their income and in turn entrepreneurs' income is related to aggregate income.

For convenience, we define  $f^i \equiv \kappa^i(1 - \alpha)/(1 - h^i) \in (0, \infty)$  as a composite parameter that is increasing in the default cost  $h^i$ . Equations (14) and (16) show that the balanced-growth level of R&D spending  $Z_t^i$  satisfies

$$Z_t^i = \min \left\{ \pi(\beta^i) \frac{\bar{g}}{\rho + \epsilon^i}, f^i \left( \frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right\} N_t^i. \quad (17)$$

There exists a unique value of patent breadth  $\beta^i$  below (above) which the credit constraint does not bind (is binding) in the long run. This threshold value of  $\beta^i$  is given by<sup>12</sup>

$$\beta_{1+}^i(f^i, \epsilon^i) \equiv \frac{\alpha \bar{g}}{\alpha \bar{g} - (\rho + \epsilon^i)f^i}, \quad (18)$$

---

<sup>12</sup>To ensure that the threshold value  $\beta_1 < 1/\alpha$ , we assume  $f^i < (1 - \alpha)\alpha\bar{g}/(\rho + \epsilon^i)$ , which is equivalent to  $h^i < 1 - (\rho + \epsilon^i)/(\alpha\bar{g})$ .

which is increasing in the country's default cost  $f^i$  and the interest-rate spread  $\epsilon^i$ . The intuition of these two results can be explained as follows. First, a larger default cost  $f^i$  reduces entrepreneurs' incentives to default and enables them to borrow more funding for R&D. In this case, the credit constraint is less likely to be binding, which in turn increases the threshold value of patent breadth. Second, a *lower* interest-rate spread  $\epsilon^i$  increases entrepreneurs' incentives to invest in R&D. As a result, the credit constraint becomes more likely to be binding, which in turn decreases the threshold value of patent breadth. In this case, a higher level of financial development has different implications on the threshold value of patent breadth depending on whether financial development is reflected by an increase in the default cost or a decrease in the interest-rate spread.

Finally, whenever the credit constraint is binding, the growth rate of technology in country  $i$  is given by

$$g_t^i = \frac{\Delta N_t^i}{N_t^i} = \frac{1}{\gamma(\mu_t^i)^\phi + \underline{\eta}} \left[ f^i \left( \frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right]^{1-\theta}, \quad (19)$$

which is decreasing in the level of patent breadth  $\beta^i$ , for a given  $\mu_t^i$ , capturing the *financial distortionary* effect of patent protection on innovation. Furthermore, a higher level of financial development in the form of an increase in the default cost  $f^i$  increases the growth rate of technology. We summarize these results in Proposition 2.

**Proposition 2** *In the presence of binding credit constraints, stronger patent protection leads to a lower growth rate of technology. A higher level of financial development in the form of an increase in the default cost leads to a higher growth rate of technology.*

**Proof.** Proven in text. ■

## 2.8 Convergence

Using the definition of relative technology level  $\mu_t^i$ , we can derive its law of motion given by

$$\frac{\mu_{t+1}^i}{\mu_t^i} = \frac{N_{t+1}^i}{N_t^i} / \frac{N_{t+1}}{N_t} \Leftrightarrow \mu_{t+1}^i = \left( \frac{1 + g_t^i}{1 + \bar{g}} \right) \mu_t^i. \quad (20)$$

In the absence of credit constraints, we use (12) to express the law of motion for  $\mu_t^i$  as

$$\mu_{t+1}^i = \frac{\mu_t^i}{1 + \bar{g}} \left\{ 1 + \frac{1}{[\gamma(\mu_t^i)^\phi + \underline{\eta}]^{1/\theta}} \left[ \frac{\pi(\beta^i)}{\rho + \epsilon^i} \right]^{(1-\theta)/\theta} \right\} \equiv H_1^i(\mu_t^i). \quad (21)$$

Even if the credit constraint does not bind in the long run, it may be binding in the short run when  $\mu_t^i$  is small. When the credit constraint is binding, we can use (19) to express the law of motion for  $\mu_t^i$  as

$$\mu_{t+1}^i = \frac{\mu_t^i}{1 + \bar{g}} \left\{ 1 + \frac{1}{\gamma(\mu_t^i)^\phi + \underline{\eta}} \left[ f^i \left( \frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right]^{1-\theta} \right\} \equiv H_2^i(\mu_t^i). \quad (22)$$

Combining (21) and (22) implies that country  $i$ 's technology level relative to the frontier evolves according to the following law of motion:

$$\mu_{t+1}^i = \min\{H_1^i(\mu_t^i), H_2^i(\mu_t^i)\},$$

from which we derive a threshold value  $\hat{\mu}^i$  of relative technology level below (above) which  $H_2^i < H_1^i$  ( $H_1^i < H_2^i$ ). In other words, when relative technology level  $\mu_t^i$  is below this threshold  $\hat{\mu}^i$ ,  $\mu_{t+1}^i$  evolves according to  $H_2^i(\mu_t^i)$  that is subject to the credit constraint. In contrast, when relative technology level  $\mu_t^i$  is above the threshold  $\hat{\mu}^i$ ,  $\mu_{t+1}^i$  evolves according to  $H_1^i(\mu_t^i)$  that is free from the credit constraint. The threshold value  $\hat{\mu}^i$  is given by

$$\hat{\mu}_{+}^i(\beta^i, f^i, \epsilon^i) \equiv \left\{ \frac{1}{\gamma} \left[ \frac{\pi(\beta^i)}{(f^i)^\theta (\rho + \epsilon^i)} \left( \frac{\beta^i}{\alpha} \right)^{\alpha\theta/(1-\alpha)} - \underline{\eta} \right] \right\}^{1/\phi}, \quad (23)$$

which is increasing in patent breadth  $\beta^i$  but decreasing in the default cost  $f^i$  and in the interest-rate spread  $\epsilon^i$ . Intuitively, at a higher level of patent protection, the credit constraint is more likely to be binding, which in turn expands the range of  $\mu_t^i$  within which  $\mu_{t+1}^i$  evolves according to  $H_2^i(\mu_t^i)$  that is subject to the credit constraint. In contrast, when either the default cost or the interest-rate premium increases, the credit constraint becomes less likely to be binding, which in turn shrinks the range of  $\mu_t^i$  within which  $\mu_{t+1}^i$  evolves according to  $H_2^i(\mu_t^i)$ .

In the following lemmata, we derive some properties of the functions  $\{H_1^i(\mu_t^i), H_2^i(\mu_t^i)\}$ , which will be useful in determining the value of  $\mu_t^i$  at the steady state.

**Lemma 1**  $H_1^i(\mu_t^i)$  is increasing and concave w.r.t.  $\mu_t^i$ , and satisfies the following properties:

$$H_1^i(0) = 0, H_1^i(1) < 1, \frac{\partial H_1^i}{\partial \mu_t^i} \Big|_{\mu_t^i=0} > 1.$$

**Proof.** See Appendix A. ■

**Lemma 2**  $H_2^i(\mu_t^i)$  is increasing and concave w.r.t.  $\mu_t^i$ , and satisfies the following properties:

$$H_2^i(0) = 0, \\ \frac{\partial H_2^i}{\partial \mu_t^i} \Big|_{\mu_t^i=0} = \frac{1}{1+\bar{g}} \left\{ 1 + \frac{1}{\underline{\eta}} \left[ f^i \left( \frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right]^{1-\theta} \right\}.$$

**Proof.** See Appendix A. ■

In addition to the first threshold value  $\beta_1$  of patent breadth defined in (18), we also define a second threshold value  $\beta_2$  of patent breadth below (above) which  $\frac{\partial H_2^i}{\partial \mu_t^i} \Big|_{\mu_t^i=0} > 1$  ( $\frac{\partial H_2^i}{\partial \mu_t^i} \Big|_{\mu_t^i=0} < 1$ ).

$$\beta_{2+}^i(f^i) \equiv \alpha \left[ \frac{f^i}{(\underline{\eta}\bar{g})^{1/(1-\theta)}} \right]^{(1-\alpha)/\alpha}, \quad (24)$$

which is increasing in the default cost  $f^i$ . We now consider three possibilities.

**Case 1** When  $\beta^i \leq \beta_1(f^i, \epsilon^i)$ , we have  $\hat{\mu}^i \leq \mu_1(\beta^i, \epsilon^i)$ .

In this case, although the credit constraint may be binding in the short run depending on the initial value of  $\mu_0^i$ , the credit constraint does not bind in the long run. Therefore, the steady-state value of relative technology  $\mu_t^i$  is given by  $\mu^i = \mu_1(\beta^i, \epsilon^i)$ , which is increasing in patent breadth  $\beta^i$  as shown in (13). The long-run growth rate of technology in this country is  $\bar{g}$ . Figure 1 shows that the steady state is stable.

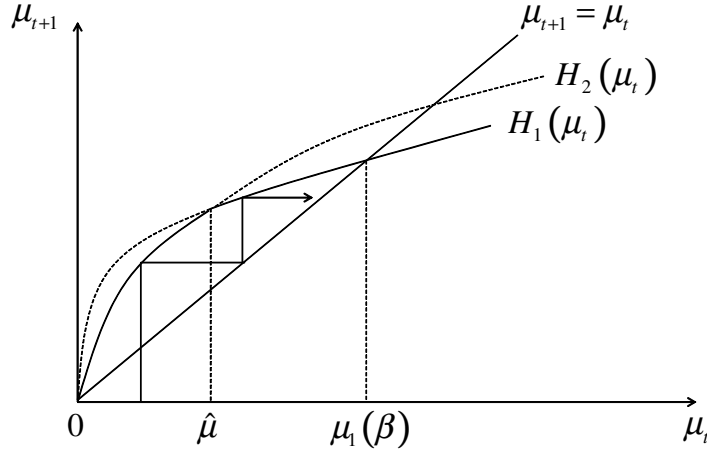


Figure 1: Convergence under  $\beta^i \leq \beta_1$

**Case 2** When  $\beta_1(f^i, \epsilon^i) < \beta^i < \beta_2(f^i)$ ,<sup>13</sup> we have  $\hat{\mu}^i > \mu_1(\beta^i)$  and  $\frac{\partial H_2^i}{\partial \mu_t^i} \big|_{\mu_t^i=0} > 1$ .

In this case, the credit constraint is binding even in the long run. The steady-state value of relative technology level  $\mu_t^i$  is determined by the fixed point  $\mu^i = H_2^i(\mu^i)$ , which yields

$$\mu^i = \left\{ \frac{1}{\gamma} \left[ \frac{1}{\bar{g}} \left[ f^i \left( \frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right]^{1-\theta} - \underline{\eta} \right] \right\}^{1/\phi} \equiv \mu_2(\beta^i, f^i), \quad (25)$$

which is decreasing in patent breadth  $\beta^i$  and increasing in the default cost  $f^i$ . The long-run growth rate of technology in this country is  $\bar{g}$ . Figure 2 shows that the steady state is stable.

<sup>13</sup>To ensure  $\beta_1 < \beta_2$ , we assume  $\underline{\eta} < f^i[\alpha\bar{g} - (\rho + \epsilon^i)f^i]^{\alpha(1-\theta)/(1-\alpha)}/\bar{g}^{(1-\alpha\theta)/(1-\alpha)}$ .

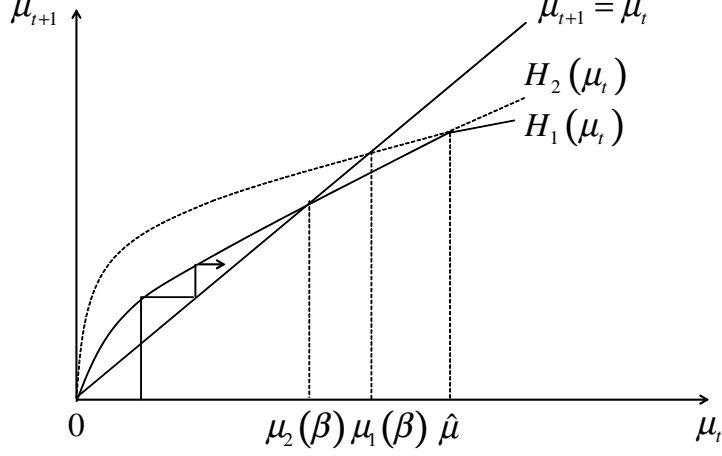


Figure 2: Convergence under  $\beta_1 < \beta^i < \beta_2$

**Case 3** When  $\beta^i \geq \beta_2(f^i)$ , we have  $\hat{\mu}^i > \mu_1(\beta^i)$  and  $\frac{\partial H_2^i}{\partial \mu_t^i} \big|_{\mu_t^i=0} \leq 1$ .

In this case,  $\mu_t^i$  converges to 0 as shown in Figure 3, and

$$\lim_{t \rightarrow \infty} \frac{\mu_{t+1}^i}{\mu_t^i} = \lim_{\mu_t^i \rightarrow 0} \frac{H_2^i(\mu_t^i)}{\mu_t^i} = \frac{1}{1 + \bar{g}} \left\{ 1 + \frac{1}{\underline{\eta}} \left[ f^i \left( \frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right]^{1-\theta} \right\} \equiv \xi^i(\beta^i, f^i) \leq 1. \quad (26)$$

Therefore, the balanced growth rate in country  $i$  in this case is

$$g^i = \lim_{t \rightarrow \infty} \left[ (1 + \bar{g}) \frac{\mu_{t+1}^i}{\mu_t^i} - 1 \right] = (1 + \bar{g}) \xi^i - 1 \leq \bar{g}, \quad (27)$$

where  $\xi^i$  is decreasing in patent breadth  $\beta^i$  and increasing in the default cost  $f^i$ .

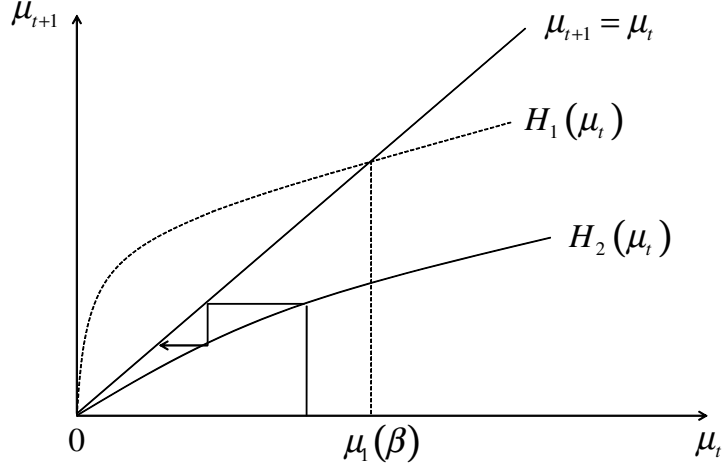


Figure 3: Divergence under  $\beta^i \geq \beta_2$

### 3 Patent breadth and credit constraints

Based on the results in the previous section, we can divide countries into three groups. Without loss of generality, we rearrange the order of the countries and denote the three groups as group 1, 2 and 3. For countries in group 1, their R&D activities are not restricted by the credit constraint, and their technologies grow at the same rate as the world technology frontier in the long run. The levels of patent protection in these countries satisfy  $\beta^i \leq \beta_1(f^i, \epsilon^i)$ , which is increasing in the default cost  $f^i$  and the interest-rate spread  $\epsilon^i$ . For countries in group 2, their R&D activities are restricted by the credit constraint, but these countries can still keep pace with the growth rate of the world technology frontier in the long run. The levels of patent protection in these countries satisfy  $\beta_1(f^i, \epsilon^i) < \beta^i < \beta_2(f^i)$ , where  $\beta_2(f^i)$  is increasing in the default cost  $f^i$  but independent of the interest-rate spread  $\epsilon^i$ . For countries in group 3, their R&D activities are strongly restricted by the credit constraint. In this case, the technology growth rate in these countries is slower than that of the world technology frontier in the long run. The levels of patent protection in these countries satisfy  $\beta^i \geq \beta_2(f^i)$ . According to this classification, the relative technology level  $\mu^i$  of a country in the steady state is given by

$$\mu^i = \begin{cases} \mu_1(\beta^i, \epsilon^i), & \text{if } \beta^i \leq \beta_1(f^i, \epsilon^i) \\ \mu_2(\beta^i, f^i), & \text{if } \beta_1(f^i, \epsilon^i) < \beta^i < \beta_2(f^i) \\ 0, & \text{if } \beta^i \geq \beta_2(f^i) \end{cases}, \quad (28)$$

and the balanced growth rate of technology is given by

$$g^i = \begin{cases} \bar{g}, & \text{if } \beta^i \leq \beta_1(f^i, \epsilon^i) \\ \bar{g}, & \text{if } \beta_1(f^i, \epsilon^i) < \beta^i < \beta_2(f^i) \\ (1 + \bar{g}) \xi^i(\beta^i, f^i) - 1 \leq \bar{g}, & \text{if } \beta^i \geq \beta_2(f^i) \end{cases} . \quad (29)$$

We summarize these results in Proposition 3.

**Proposition 3** *There are three types of balanced growth paths in the world. First, when  $\beta^i \leq \beta_1(f^i, \epsilon^i)$ , relative technology level  $\mu^i$  converges to  $\mu_1$ , and the growth rate of technology converges to  $\bar{g}$ . In this case,  $\mu_1$  is increasing in patent breadth  $\beta^i$  and decreasing in the interest-rate spread  $\epsilon^i$ . Second, when  $\beta_1(f^i, \epsilon^i) < \beta^i < \beta_2(f^i)$ , relative technology level  $\mu^i$  converges to  $\mu_2$ , and the growth rate of technology converges to  $\bar{g}$ . In this case,  $\mu_2$  is decreasing in patent breadth  $\beta^i$  and increasing in the default cost  $f^i$ . Third, when  $\beta^i \geq \beta_2(f^i)$ , relative technology level  $\mu^i$  converges to zero, and the growth rate of technology converges to  $(1 + \bar{g}) \xi^i - 1$ , which is decreasing in patent breadth  $\beta^i$  and increasing in the default cost  $f^i$ .*

**Proof.** Proven in text. ■

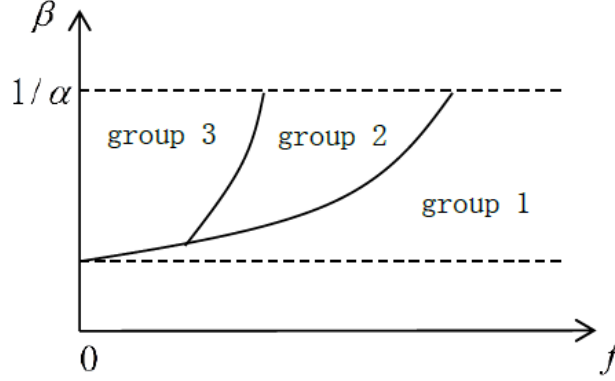


Figure 4

Figure 4 illustrates the three groups of countries. Countries in group 1 are not financially constrained due to a high default cost  $f^i$ . In this case, stronger patent protection increases the amount of monopolistic profit, which in turn stimulates R&D and increases the relative technology level  $\mu_1$  in the long run. A higher level of financial development in the form of a lower interest-rate spread  $\epsilon^i$  increases the value of inventions and the relative technology level  $\mu_1$  in the long run. Countries in group 2 are financially constrained due to a moderate default cost  $f^i$ . In this case, stronger patent protection amplifies monopolistic distortion and reduces the level of output, which in turn tightens the credit constraint on R&D and decreases the relative technology level  $\mu_2$  in the long run. A higher level of financial development in the form of a higher default cost  $f^i$  enables the



entrepreneurs to borrow more funding for R&D, which in turn increases the relative technology level  $\mu_2$  in the long run.

For a given value of the default cost  $f^i$ , an increase in the level of patent protection may cause a country in group 1 to fall into group 2. Therefore, there exists a technology-maximizing level of patent protection  $\beta_1$ . This technology-maximizing level of patent protection  $\beta_1$  is affected by the level of financial development. First, it is increasing in the default cost  $f^i$ . As mentioned before, a larger default cost  $f^i$  reduces entrepreneurs' incentives to default, which enables them to borrow more funding for R&D. In this case, the credit constraint is less likely to be binding, which in turn increases the threshold value  $\beta_1$  of patent breadth. Second, the technology-maximizing level of patent protection  $\beta_1$  is increasing in the interest-rate spread  $\epsilon^i$ . Intuitively, a higher interest rate decreases the value of inventions and reduces entrepreneurs' incentives to invest in R&D. As a result, the credit constraint becomes less likely to bind, rendering patent protection to be more likely to have a positive effect on R&D. A higher level of financial development *increases* the cost of default but *decreases* the interest-rate spread in a country. Therefore, under a higher level of financial development, it is not clear whether patent protection would become more likely to have a positive or negative effect on innovation. This depends on whether financial development increases the default cost or decreases the interest-rate spread. We summarize all the above results in Proposition 4.

**Proposition 4** *Financial development has a positive effect on innovation whereas patent protection has an inverted-U effect on innovation. If financial development increases the default cost, then patent protection would be more likely to have a positive effect on innovation under a higher level of financial development. If financial development decreases the interest-rate spread, then patent protection would be more likely to have a negative effect on innovation under a higher level of financial development.*

**Proof.** Proven in text. ■

Finally, countries in group 3 have a very low default cost  $f^i$ . Given that R&D entrepreneurs have strong incentives to default in this case, they are not able to borrow much funding for R&D. In this case, the steady-state growth rate is given by  $(1 + \bar{g})\xi^i - 1 \leq \bar{g}$ , where  $\xi^i$  is decreasing in the level of patent breadth. An increase in the default cost helps to mitigate this problem and raises the steady-state growth rate.

## 4 Empirical analysis

In this section we examine the empirical evidence of our theoretical predictions. The implications of our theory that will be tested are the followings:

1. The likelihood that a country converges to the frontier growth rate increases with its level of financial development but decreases with its level of patent protection.
2. In a country that converges to the frontier growth rate, financial development has a positive effect on the steady-state level of per-capita GDP relative to the frontier.

3. In a country that converges to the frontier growth rate, patent protection has an ambiguous effect on the steady-state level of per-capita GDP relative to the frontier.
4. Under a higher level of financial development, patent protection can be more likely to have a negative or positive effect on the steady-state level of relative per-capita GDP.

## 4.1 Data

The dataset consists of 98 countries from 1980 to 2009 featuring variables of economic growth, patent protection, financial development and other controls.<sup>14</sup> We transform the dataset into a cross section by taking annual average of each variable for each country. The growth rate of a country is taken to be the average annual growth rate of GDP per capita between 1980 and 2009. For the measure of patent protection within a country, we consider the commonly used index of patent rights developed by Ginarte and Park (1997) and Park (2008).<sup>15</sup> The data for financial development is based on the Financial Development and Structure Dataset from Cihak *et al.* (2012).

Following King and Levine (1993) and Beck *et al.* (2010), we take advantage of three indicators of financial intermediation that can proxy the overall development of a country's financial system. The first measure is the private credit by deposit money banks and other financial institutions as a ratio to GDP, denoted as *private credit*. The second indicator is deposit money banks' assets as a ratio to GDP, denoted as *bank assets*. The third indicator is liquid liabilities as a ratio to GDP, denoted as *liquid liabilities*. We use *private credit* as our preferred measure of financial development as in Ang (2010, 2011) and consider the other two measures as robustness checks because as stated in Levine *et al.* (2000), *private credit* excludes credit granted to the public sector and credit granted by the central bank and development banks.

In our theoretical model, the amount of borrowing as a ratio to output is given by

$$\frac{D_t^i}{Y_t^i} = \frac{Z_t^i - \kappa^i W_t^i}{Y_t^i} = \min \left\{ \pi (\beta^i) \frac{\bar{g}}{\rho + \epsilon^i} \left( \frac{\beta^i}{\alpha} \right)^{\alpha/(1-\alpha)}, f^i \right\} - \kappa^i (1 - \alpha),$$

where the second equality follows from (17) and (6). Therefore,  $D_t^i/Y_t^i$  is increasing in the default cost  $f^i$  and decreasing in the interest-rate spread  $\epsilon^i$ . In other words, an increase in  $D_t^i/Y_t^i$  in the data may reflect the effect of a larger  $f^i$  or the effect of a smaller  $\epsilon^i$ .

## 4.2 Convergence regression

We first use the convergence regression model based on Aghion *et al.* (2005) to test our theoretical implications. The starting point of this model is that each country is assumed to be on a transition

<sup>14</sup>See Appendix B for description and sources of data.

<sup>15</sup>The index covers five dimensions: 1) extent of coverage; 2) membership in international patent agreements; 3) provisions for loss of protection; 4) enforcement mechanisms; and 5) duration of protection. Each dimension is assigned a value between zero and one. The overall index is the unweighted sum of these five values, with a larger value reflecting a higher level of patent protection.

path towards its steady state. From (20)-(22), patent protection and financial development affect the relative growth rate of a country that is converging to the frontier given by  $(1 + g_t^i)/(1 + \bar{g}) = \mu_{t+1}^i/\mu_t^i$ . In particular, (21) and (22) show that the initial relative technology level has a negative effect on the transitional relative growth rate and that financial development always has a positive effect regardless of whether it increases the default cost  $f^i$  or decreases the interest-rate spread  $\epsilon^i$ . In countries without binding credit constraints, patent protection positively affects the transitional relative growth rate, whereas in countries with binding credit constraints, patent protection negatively affects the transitional relative growth rate. This empirical analysis is an extension of Aghion *et al.* (2005) with the addition of patent protection, so we follow them to approximate our theoretical model by the following cross-sectional regression, which can be used to investigate the effects of patent protection and financial development on the steady-state level of per-capita GDP growth relative to the frontier:

$$\begin{aligned} g_i - g_1 = & \gamma_0 + \gamma_\beta \beta_i + \gamma_F F_i + \gamma_{\beta F} \beta_i \cdot F_i + \gamma_y \cdot (y_i - y_1) \\ & + \gamma_{\beta y} \cdot \beta_i \cdot (y_i - y_1) + \gamma_{Fy} \cdot F_i \cdot (y_i - y_1) + \gamma_x x_i + \varepsilon_i, \end{aligned} \quad (30)$$

where  $g_i$  denotes the average annual growth rate of per-capita GDP,  $\beta_i$  denotes the average level of patent protection,  $F_i$  denotes the average level of financial development,  $y_i$  is the log of initial per-capita GDP,  $x_i$  is a set of other control variables and  $\varepsilon_i$  is the disturbance term with mean zero. The subscript  $i$  denotes country, and country 1 is the technology leader, which we take to be the United States.

Define country  $i$ 's initial relative per-capita GDP as  $\hat{y}_i \equiv y_i - y_1$ . Then we can rewrite (30) as

$$g_i - g_1 = \lambda_i \cdot (\hat{y}_i - \hat{y}_i^*),$$

where the steady-state value  $\hat{y}_i^*$  is given by setting the right-hand side of (30) to zero (i.e., when the growth rate difference is zero):

$$\hat{y}_i^* = \frac{\gamma_0 + \gamma_\beta \beta_i + \gamma_F F_i + \gamma_{\beta F} \beta_i \cdot F_i + \gamma_x x_i + \varepsilon_i}{-(\gamma_y + \gamma_{\beta y} \cdot \beta_i + \gamma_{Fy} \cdot F_i)}. \quad (31)$$

In (30),  $\lambda_i$  is a country-specific convergence parameter given by

$$\lambda_i = \gamma_y + \gamma_{\beta y} \cdot \beta_i + \gamma_{Fy} \cdot F_i. \quad (32)$$

It is useful to note that a country converges to the technology frontier if and only if the growth rate of its relative per-capita GDP depends negatively on the initial  $\hat{y}_i$ ; that is, if and only if  $\lambda_i < 0$ . Thus, from implication 1 we know that the likelihood of convergence would increase with financial development and decrease with patent protection if and only if

$$\gamma_{Fy} < 0 \text{ and } \gamma_{\beta y} > 0. \quad (33)$$

From (31), the long-run effects of financial development and patent protection on the relative output of a country that converges are as follows:

$$\frac{\partial \hat{y}_i^*}{\partial F_i} = - \underbrace{\frac{1}{\lambda_i}}_{+} \underbrace{(\gamma_F + \gamma_{\beta F} \beta_i + \gamma_{Fy} \hat{y}_i^*)}_{?}, \quad (34)$$

and

$$\frac{\partial \hat{y}_i^*}{\partial \beta_i} = -\frac{1}{\underbrace{\lambda_i}_{+}} \underbrace{(\gamma_\beta + \gamma_{\beta F} F_i + \gamma_{\beta y} \hat{y}_i^*)}_{?}. \quad (35)$$

### 4.3 Relative-technology-level regression

In addition to the convergence regression, we also consider the following relative-technology-level regression:

$$\bar{y}_i - \bar{y}_1 = \zeta_0 + \zeta_\beta \beta_i + \zeta_F F_i + \zeta_{\beta F} \beta_i \cdot F_i + \zeta_y \cdot (y_i - y_1) + \zeta_x x_i + \nu_i, \quad (36)$$

where  $\bar{y}_i$  is the average log of per-capita GDP,  $\nu_i$  is another disturbance term with mean zero, and the other variables are defined in the same way as in the convergence regression. This regression model also captures the implications from (21) and (22) that patent protection and financial development affect a country's relative technology level with respect to the technology frontier. It is useful to note that our data sample covers 30 years, so we try to approximate the steady-state level of relative per-capita GDP by  $\bar{y}_i - \bar{y}_1$ , and hence, this regression model is used as an additional test of implications 2-4.

### 4.4 Regression results

Considering the endogeneity of financial development as discussed in Aghion *et al.* (2005) and also the endogeneity of patent protection, we estimate the regression models using instrumental variables. We use legal origins as the instrument for financial development  $F_i$ . As for the instruments for patent protection  $\beta_i$ , we combine two sets of instruments. The first set of instruments is chosen according to Gould and Gruben (1996), including initial relative output  $y_i - y_1$  and initial degree of openness. We do not use the other instruments in their paper to avoid overidentification. The second set of instruments is a simulated instrumental variable (SIV). For country  $i$ , we use the average degree of patent protection of all the other countries (except country  $i$ ) in 1980 as an instrument for country  $i$ 's average patent protection over 1980-2009. We refer to this instrument as simulated patent protection and denote it as *siv\_ipr<sub>i</sub>*. This variable is to control for the endogenous response of patent protection to changes in innovation activities within a country, and we assume that the changes are not correlated across countries.<sup>16</sup> The interacted terms between instruments are also used as instruments for the interacted terms of the endogenous variables. Tables I and III report the estimation results from the generalized method of moments (GMM), and Tables II and IV report the results from two-stage least squares (2SLS). We consider both GMM and 2SLS for robustness.

---

<sup>16</sup>For a discussion of SIV, see for example Currie and Jonathan (1996) and Mahoney (2015). We use SIV to deal with the issue of weak instruments. We find that if we only use initial relative GDP and initial openness as instruments for patent protection, the two variables suffer from the problem of weak instruments. Moreover, we tried using lagged patent protection, which is the degree of patent protection within each country (from 1960 to 1979) before our sample period. All these regressions results are available upon request.

*[Insert Tables I and II here]*

From Tables I and II, we find that the following results are robust and significant for most of the regressions: (1)  $\gamma_{\beta y} > 0$ ,  $\gamma_{Fy} < 0$ ,  $\gamma_y < 0$ ; and (2)  $\gamma_\beta > 0$ ,  $\gamma_F > 0$ ,  $\gamma_{\beta F} < 0$ . The first set of results  $\{\gamma_{\beta y} > 0, \gamma_{Fy} < 0, \gamma_y < 0\}$  supports implication 1. It is useful to recall that a country converges to the technology frontier if and only if  $\lambda_i = \gamma_y + \gamma_{\beta y} \cdot \beta_i + \gamma_{Fy} \cdot F_i < 0$ . Therefore,  $\gamma_{Fy} < 0$  and  $\gamma_{\beta y} > 0$  imply that the likelihood of convergence increases with financial development but decreases with patent protection.

To understand the implications of the second set of results  $\{\gamma_\beta > 0, \gamma_F > 0, \gamma_{\beta F} < 0\}$ , let's begin by assuming that all countries lag behind the United States in the steady state; i.e.,  $\hat{y}_i^* < 0$ . Financial development would have a positive long-run effect on the relative income of each country that converges if and only if  $\gamma_F + \gamma_{\beta F}\beta_i + \gamma_{Fy}\hat{y}_i^* > 0$ . In this term,  $\gamma_{\beta F}\beta_i$  is negative because the estimated  $\gamma_{\beta F}$  is negative, whereas  $\gamma_{Fy}\hat{y}_i^*$  is positive because the estimated  $\gamma_{Fy}$  is negative. The result  $\gamma_F > 0$  implies that financial development is likely to have a positive long-run effect, and this positive effect is unlikely to vanish or become negative because  $\gamma_F + \gamma_{Fy}\hat{y}_i^* > 0$ . This finding is consistent with implication 2. We also consider the magnitude of the coefficients. From regression 1 of Table II, we have  $\gamma_F + \gamma_{\beta F}\beta_i = 0.0750 - 0.0210 \cdot \beta_i$ . Given a mean of 2.568 for  $\beta_i$ ,  $\gamma_F + \gamma_{\beta F}\beta_i$  is positive for the average country. Together with  $\gamma_{Fy}\hat{y}_i^* > 0$ , financial development has a positive long-run effect on the relative income of the average country. Moreover, we use equation (34) to compute the long-run effect of financial development and find that financial development has a positive long-run effect in the vast majority of countries.

As for patent protection, it would have a positive long-run effect on each country that converges if and only if  $\gamma_\beta + \gamma_{\beta F}F_i + \gamma_{\beta y}\hat{y}_i^* > 0$ . In this term,  $\gamma_{\beta F}F_i$  is negative because the estimated  $\gamma_{\beta F}$  is negative, and  $\gamma_{\beta y}\hat{y}_i^*$  is also negative because the estimated  $\gamma_{\beta y}$  is positive. The result  $\gamma_\beta > 0$  implies that patent protection may have a positive long-run effect, but this positive effect may turn negative because  $\gamma_{\beta F}F_i + \gamma_{\beta y}\hat{y}_i^* < 0$ . From regression 1 of Table II, we have  $\gamma_\beta + \gamma_{\beta F}F_i = 0.0204 - 0.0210 \cdot F_i$ . Given a mean of 0.448 for  $F_i$ , the average country has  $\gamma_\beta + \gamma_{\beta F}F_i > 0$ . However, given that  $\gamma_{\beta y}\hat{y}_i^* < 0$  and that  $F_i$  can be as large as 1.776, patent protection would have a negative long-run effect in countries with sufficiently large  $F_i$ . In other words, patent protection has a negative (positive) long-run effect when the level of financial development  $F_i$  is high (low). Using equation (35) to compute the long-run effect of patent protection, we find that patent protection has a positive (negative) long-run effect in about one-third (two-thirds) of countries, and these countries have a low (high) level of financial development. This finding is consistent with implications 3 and 4 as well as the scenario in which the interest-spread channel dominates in influencing credit constraints. In other words, when the level of financial development is low (i.e., a high interest-rate spread in the model), patent protection has a positive long-run effect. When the level of financial development is high (i.e., a low interest-rate spread in the model), the effect of patent protection becomes negative.

*[Insert Tables III and IV here]*

From Tables III and IV, we find that  $\zeta_\beta > 0$ ,  $\zeta_F > 0$ ,  $\zeta_{\beta F} < 0$  and  $\zeta_y > 0$ . The implications of this set of results are similar to the above, so we do not repeat the discussion and simply report

the results as a robustness check. Finally, we also estimate the likelihood of convergence for each country. We use the coefficients in regression 1 of Table II to compute the estimated value of convergence parameter  $\lambda_i$ , and its standard deviation. We follow Aghion *et al.* (2005) to classify a country as most likely to converge in growth if its estimated  $\lambda_i$  is at least two standard deviations below zero, as most likely to diverge in growth if its estimated  $\lambda_i$  is at least two standard deviations above zero, and as uncertain to converge otherwise. As reported in Table V, we find that none of the countries in our sample is classified as most likely to diverge, and there are 54 countries (out of 103) that are classified as most likely to converge.

*[Insert Table V here]*

## 5 Conclusion

In this study, we have explored the effects of patent protection and financial development on economic growth. The novelty of our analysis is that we consider the presence of credit constraints on R&D entrepreneurs. We find that whether strengthening patent protection has a positive or negative effect on technological progress depends on credit constraints. When credit constraints are not binding, strengthening patent protection has a positive effect on economic growth. When credit constraints are binding, strengthening patent protection has a negative effect on growth. An increase in the level of patent protection may cause the credit constraints to become binding. As a result, the overall effect of patent protection on economic growth follows an inverted-U pattern. A higher level of financial development influences credit constraints via two channels: decreasing the interest-rate spread and increasing the default cost. These two channels have different implications on the effects of patent protection. Our regression analysis finds evidence that strengthening patent protection is more likely to have a negative effect on innovation under a higher level of financial development, which is consistent with the interest-spread channel. These results show the importance of an often neglected interaction between the monopolistic distortion caused by patent protection and the financial distortion caused by credit constraints.

## References

- [1] Acemoglu, D., 2009. *Introduction to Modern Economic Growth*. Princeton University Press.
- [2] Acemoglu, D., Aghion, P., and Zilibotti, F., 2006. Distance to frontier, selection, and economic growth. *Journal of the European Economic Association*, 4, 37-74.
- [3] Aghion, P., Howitt, P., and Mayer-Foulkes, D., 2005. The effect of financial development on convergence: Theory and evidence. *Quarter Journal of Economics*, 120, 173-222.
- [4] Ang, J., 2010. Financial reforms, patent protection and knowledge accumulation in India. *World Development*, 38, 1070-1081.
- [5] Ang, J., 2011. Financial development, liberalization and technological deepening. *European Economic Review*, 55, 688-701.
- [6] Barro, R., and Lee, J.-W., 2013. A new data set of educational attainment in the world, 1950-2010. *Journal of Development Economics*, 104, 184-198.
- [7] Beck, T., Demirguc-Kunt, A., and Levine, R., 2010. Financial institutions and markets across countries and over time: The updated financial development and structure database. *World Bank Economic Review*, 24, 77-92.
- [8] Bessen, J., and Meurer, M., 2008. *Patent Failure: How Judges, Bureaucrats, and Lawyers Put Innovators at Risk*. Princeton University Press.
- [9] Boldrin, M., and Levine, D., 2008. *Against Intellectual Monopoly*. Cambridge University Press.
- [10] Chu, A., 2009. Effects of blocking patents on R&D: A quantitative DGE analysis. *Journal of Economic Growth*, 14, 55-78.
- [11] Chu, A., Cozzi, G., and Galli, S., 2012. Does intellectual monopoly stimulate or stifle innovation? *European Economic Review*, 56, 727-746.
- [12] Chu, A., Cozzi, G., and Galli, S., 2014. Stage-dependent intellectual property rights. *Journal of Development Economics*, 106, 239-249.
- [13] Chu, A., and Pan, S., 2013. The escape-infringement effect of blocking patents on innovation and economic growth. *Macroeconomic Dynamics*, 17, 955-969.
- [14] Cihak, M., Demirg-Kunt, A., Feyen, E., and Levine, R., 2012. Benchmarking financial development around the world. Policy Research Working Paper 6175.
- [15] Cozzi, G., and Galli, S., 2014. Sequential R&D and blocking patents in the dynamics of growth. *Journal of Economic Growth*, 19, 183-219.
- [16] Currie, J., and Gruber, J., 1996. Saving babies: The efficacy and cost of recent expansions of Medicaid eligibility for pregnant women. *Journal of Political Economy*, 104, 1263-1296.

- [17] Davis, L., and Sener, F., 2012. Private patent protection in the theory of Schumpeterian growth. *European Economic Review*, 56, 1446-1460.
- [18] Dinopoulos, E., and Syropoulos, C., 2007. Rent protection as a barrier to innovation and growth. *Economic Theory*, 32, 309-332.
- [19] Furukawa, Y., 2007. The protection of intellectual property rights and endogenous growth: Is stronger always better? *Journal of Economic Dynamics and Control*, 31, 3644-3670.
- [20] Gilbert, R., and Shapiro, C. 1990. Optimal patent length and breadth. *RAND Journal of Economics*, 21, 106-112.
- [21] Ginarte, J., and Park, W., 1997. Determinants of patent rights: A cross-national study. *Research Policy*, 26, 283-301.
- [22] Goh, A.-T., and Olivier, J., 2002. Optimal patent protection in a two-sector economy. *International Economic Review*, 43, 1191-1214.
- [23] Gould, D., and Gruben, W. 1996. The role of intellectual property rights in economic growth. *Journal of Development Economics*, 48, 323-350.
- [24] Heston, A., Summers, R., and Aten, B., 2012. Penn World Table version 7.1. Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania.
- [25] Horii, R., and Iwaisako, T., 2007. Economic growth with imperfect protection of intellectual property rights. *Journal of Economics*, 90, 45-85.
- [26] Iwaisako, T., and Futagami, K., 2013. Patent protection, capital accumulation, and economic growth. *Economic Theory*, 52, 631-668.
- [27] Jaffe, A., and Lerner, J., 2004. *Innovation and Its Discontents: How Our Broken System Is Endangering Innovation and Progress, and What to Do About It*. Princeton University Press.
- [28] Jones, C., and Williams, J., 2000. Too much of a good thing? The economics of investment in R&D. *Journal of Economic Growth*, 5, 65-85.
- [29] Judd, K., 1985. On the performance of patents. *Econometrica*, 53, 567-586.
- [30] Kiedaisch, C., 2015. Intellectual property rights in a quality-ladder model with persistent leadership. *European Economic Review*, 80, 194-213.
- [31] King, R., and Levine, R., 1993. Finance and growth: Schumpeter might be right. *Quarterly Journal of Economics*, 108, 717-737.
- [32] Klemperer, P., 1990. How broad should the scope of patent protection be? *RAND Journal of Economics*, 21, 113-130.
- [33] La Porta, R., Lopez-de-Silanes, F., Shleifer, A., and Vishny, R., 1999. The quality of government. *Journal of Law, Economics, and Organization*, 15, 222-279.



- [34] Lerner, J., 2009. The empirical impact of intellectual property rights on innovation: Puzzles and clues. *American Economic Review*, 99, 343-348.
- [35] Lerner, J., and Schoar, A., 2005. Does legal enforcement affect financial transactions? The contractual channel in private equity. *Quarterly Journal of Economics*, 120, 223-46.
- [36] Levine, R., Loayza, N., and Beck, T., 2000. Financial intermediation and growth: Causality and causes. *Journal of Monetary Economics*, 46, 31-77.
- [37] Li, C.-W., 2001. On the policy implications of endogenous technological progress. *Economic Journal*, 111, C164-C179.
- [38] Liberti, J., and Mian, A., 2010. Collateral spread and financial development. *Journal of Finance*, 65, 147-177.
- [39] Mahoney, N., 2015. Bankruptcy as implicit health insurance. *American Economic Review*, 105, 710-746.
- [40] Nordhaus, W., 1969. *Invention, Growth, and Welfare*. The MIT Press.
- [41] O'Donoghue, T., and Zweimuller, J., 2004. Patents in a model of endogenous growth. *Journal of Economic Growth*, 9, 81-123.
- [42] Park, W., 2009. International patent protection: 1960-2005. *Research Policy*, 27, 761-766.
- [43] Park, W., and Ginarte, J., 1997. Intellectual property rights and economic growth. *Contemporary Economic Policy*, 15, 51-61.
- [44] Qian, J., and Strahan, P., 2007. How law and institutions shape financial contracts: The case of bank loans. *Journal of Finance*, 62, 2803-2834.
- [45] Qian, Y., 2007. Do national patent laws stimulate domestic innovation in a global patenting environment? A cross-country analysis of pharmaceutical patent protection, 1978-2002. *Review of Economics and Statistics*, 89, 436-453.
- [46] Romer, P., 1990. Endogenous technological change. *Journal of Political Economy*, 98, S71-S102.
- [47] Scotchmer, S., 2004. *Innovation and Incentives*. The MIT Press.

## Appendix A: Proofs

**Proof of Lemma 1.** From (21), we see that  $H_1^i(0) = 0$ . Simple differentiations yield

$$\frac{\partial H_1^i}{\partial \mu_t^i} = \frac{1}{1+\bar{g}} \left\{ 1 + \frac{(1-\phi)\gamma(\mu_t^i)^\phi + \underline{\eta}}{[\gamma(\mu_t^i)^\phi + \underline{\eta}]^{(1+\theta)/\theta}} \left[ \frac{\pi(\beta^i)}{\rho + \epsilon^i} \right]^{(1-\theta)/\theta} \right\} > 0, \quad (\text{A1})$$

$$\frac{\partial^2 H_1^i}{\partial (\mu_t^i)^2} = -\frac{\gamma\phi(\mu_t^i)^{\phi-1}}{1+\bar{g}} \frac{(1-\phi)\gamma(\mu_t^i)^\phi/\theta + (\phi+1/\theta)\underline{\eta}}{[\gamma(\mu_t^i)^\phi + \underline{\eta}]^{(1+2\theta)/\theta}} \left[ \frac{\pi(\beta^i)}{\rho + \epsilon^i} \right]^{(1-\theta)/\theta} < 0. \quad (\text{A2})$$

Evaluating (A1) at  $\mu_t^i = 0$  yields

$$\frac{\partial H_1^i}{\partial \mu_t^i} \Big|_{\mu_t^i=0} = \frac{1}{1+\bar{g}} \left\{ 1 + \frac{1}{\underline{\eta}^{1/\theta}} \left[ \frac{\pi(\beta^i)}{\rho + \epsilon^i} \right]^{(1-\theta)/\theta} \right\} > 1, \quad (\text{A3})$$

which is satisfied due to the assumption  $\pi(\beta^i)/(\rho + \epsilon^i) > (\bar{g}^\theta \underline{\eta})^{1/(1-\theta)}$  that ensures  $\mu_1(\beta^i) > 0$ . Evaluating  $H_1^i(\mu_t^i)$  at  $\mu_t^i = 1$  yields

$$H_1^i(1) = \frac{1}{1+\bar{g}} \left\{ 1 + \frac{1}{(\gamma + \underline{\eta})^{1/\theta}} \left[ \frac{\pi(\beta^i)}{\rho + \epsilon^i} \right]^{(1-\theta)/\theta} \right\} < 1, \quad (\text{A4})$$

which is satisfied due to the assumption  $\pi(\beta^i)/(\rho + \epsilon^i) < [\bar{g}^\theta(\gamma + \underline{\eta})]^{1/(1-\theta)}$ . ■

**Proof of Lemma 2.** From (22), we see that  $H_2^i(0) = 0$ . Simple differentiations yield

$$\frac{\partial H_2^i}{\partial \mu_t^i} = \frac{1}{1+\bar{g}} \left\{ 1 + \frac{(1-\phi)\gamma(\mu_t^i)^\phi + \underline{\eta}}{[\gamma(\mu_t^i)^\phi + \underline{\eta}]^2} \left[ f^i \left( \frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right]^{1-\theta} \right\} > 0, \quad (\text{A5})$$

$$\frac{\partial^2 H_2^i}{\partial (\mu_t^i)^2} = -\frac{\gamma\phi(\mu_t^i)^{\phi-1}}{1+\bar{g}} \frac{(1-\phi)\gamma(\mu_t^i)^\phi + (1+\phi)\underline{\eta}}{[\gamma(\mu_t^i)^\phi + \underline{\eta}]^3} \left[ f^i \left( \frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right]^{1-\theta} < 0. \quad (\text{A6})$$

Evaluating (A5) at  $\mu_t^i = 0$  yields

$$\frac{\partial H_2^i}{\partial \mu_t^i} \Big|_{\mu_t^i=0} = \frac{1}{1+\bar{g}} \left\{ 1 + \frac{1}{\underline{\eta}} \left[ f^i \left( \frac{\alpha}{\beta^i} \right)^{\alpha/(1-\alpha)} \right]^{1-\theta} \right\}. \quad (\text{A7})$$

■

## Appendix B: Description of the dataset

The empirical analysis is based on a panel dataset for 103 countries over 1980-2009. Variables used for regression are listed below with definitions and data sources. The variables of annual change rate (i.e., economic growth rate and inflation rate) are calculated through log differences. In the cross-section regressions, the annual variables are all averaged over the sample period.

- $g_i$ : the averaged annual growth rate of real per capita GDP. Source: Penn World Table 7.1.
- $y_i$ : the log of real per capita GDP at the initial period (1980). Source: Penn World Table 7.1.
- $\bar{y}_i$ : the average log of real per capita GDP. Source: Penn World Table 7.1.
- $\beta_i$ : the average degree of patent protection over 1980-2009, measured by the average index of patent rights. Source: Park (2008).
- $siv\_ipr_i$ : the average degree of simulated patent protection, measured by the average index of patent rights of all countries except country  $i$  in 1980. Source: Park (2008).
- $F_i$ : the average level of financial development. There are three measures: 1) the average value of private credit by deposit money banks and other financial institutions as a share of GDP (*private credit*); 2) the average value of deposit money banks' assets as a share of GDP (*bank assets*); 3) the average value of liquid liabilities as a share of GDP (*liquid liabilities*). Source: Cihak *et al.* (2012).
- $sec_i$ : the average years of secondary schooling in the population over 15 in the initial period (1980). Source: Barro and Lee (2013).
- $inf_i$ : the average inflation rate over 1980-2009, defined as log difference of GDP deflator. Source: Penn World Table 7.1.
- $gov_i$ : the average government expenditure as a share of GDP over 1980-2009. Source: Penn World Table 7.1.
- $open_i$ : the average openness to trade over 1980-2009, defined as sum of real exports and imports as a share of GDP. Source: Penn World Table 7.1.
- $legal_i$ : Dummy variables for British, French, German, Scandinavian and Socialist legal origins. Source: La Porta *et al.* (1999).

### Summary statistics

Variable	# of obs	Mean	Std. dev.	Min	Max
$\beta_i$	103	2.568	0.907	0.5	4.721
$F_i$ (private credit)	103	0.448	0.388	0.013	1.776
$F_i$ (bank assets)	103	0.502	0.396	0.016	1.981
$F_i$ (liquid liabilities)	103	0.511	0.395	0.063	2.721
$g_i$	103	0.014	0.017	-0.037	0.084
$y_i$	103	8.309	1.256	6.006	10.371
$\bar{y}_i$	103	8.458	1.346	5.816	10.804
$\beta_i^{old}$	103	1.897	0.009	1.872	1.917
$sec_i$	103	1.409	1.073	0.06	5.19
$inf_i$	103	0.030	0.003	0.017	0.038
$gov_i$	103	0.099	0.052	0.035	0.325
$open_i$	103	0.686	0.435	0.186	2.926

### Legal origin classifications

- **British:** Australia, Bangladesh, Botswana, Canada, Cyprus, United Kingdom, Ghana, Guyana, India, Ireland, Israel, Jamaica, Kenya, Liberia, Sri Lanka, Malawi, Malaysia, Nepal, New Zealand, Pakistan, Papua New Guinea, Sudan, Singapore, Sierra Leone, Swaziland, Thailand, Trinidad and Tobago, Tanzania, Uganda, United States, South Africa, Zambia, Zimbabwe.
- **French:** Argentina, Burundi, Belgium, Benin, Bolivia, Brazil, Central African Republic, Cote d'Ivoire, Cameroon, Congo Republic, Colombia, Costa Rica, Dominican Republic, Algeria, Ecuador, Egypt, Spain, France, Gabon, Greece, Guatemala, Honduras, Haiti, Indonesia, Iran, Iraq, Italy, Jordan, Luxembourg, Morocco, Mexico, Mali, Malta, Mozambique, Mauritania, Mauritius, Niger, Nicaragua, Netherlands, Panama, Peru, Philippines, Portugal, Paraguay, Rwanda, Senegal, El Salvador, Syria, Togo, Tunisia, Turkey, Uruguay, Venezuela, Zaire.
- **German:** Austria, Switzerland, Germany, Japan, Korea.
- **Scandinavian:** Denmark, Finland, Iceland, Norway, Sweden.
- **Socialist:** Bulgaria, China, Hungary, Poland, Romania, Vietnam.

## Appendix C: Regression results

Table I: Convergence regression: GMM

**Regression equation:**  $g_i - g_1 = \gamma_0 + \gamma_\beta \beta_i + \gamma_F F_i + \gamma_{\beta F} \beta_i \cdot F_i + \gamma_y \cdot (y_i - y_1) + \gamma_{\beta y} \cdot \beta_i \cdot (y_i - y_1) + \gamma_{Fy} \cdot F_i \cdot (y_i - y_1) + \gamma_x x_i + \varepsilon_i.$

	1	2	3	4	5	6
	Private credit		Bank assets		Liquid liabilities	
Control regressors	Empty	Full	Empty	Full	Empty	Full
Coefficient estimates						
$\gamma_\beta$	0.0188*** (8.40)	0.0166*** (5.52)	0.0200*** (7.98)	0.0174*** (4.46)	0.0127*** (4.69)	0.0182*** (3.70)
$\gamma_F$	0.0672*** (4.58)	0.0592*** (2.75)	0.0808*** (6.11)	0.0715*** (2.99)	0.0454* (1.89)	0.0929** (2.34)
$\gamma_{\beta F}$	-0.0190*** (-5.67)	-0.0176*** (-3.45)	-0.0214*** (-6.74)	-0.0191*** (-3.31)	-0.0125** (-2.09)	-0.0238** (-2.40)
$\gamma_y$	-0.0156*** (-5.89)	-0.0127*** (-3.69)	-0.0137*** (-4.34)	-0.0107** (-2.55)	-0.00376 (-1.24)	-0.00769* (-1.87)
$\gamma_{\beta y}$	0.00750*** (6.09)	0.00628*** (4.60)	0.00594*** (4.64)	0.00490*** (3.28)	0.00388*** (2.86)	0.00432*** (2.78)
$\gamma_{Fy}$	-0.0242*** (-7.32)	-0.0237*** (-6.76)	-0.0191*** (-7.97)	-0.0200*** (-5.88)	-0.0215*** (-6.96)	-0.0150*** (-3.07)
Hansen's $J$ -test (p-value)	0.6001	0.5504	0.5465	0.3622	0.6198	0.5562
GMM $C$ -test (p-value)	0.0323	0.2441	0.0659	0.5543	0.0611	0.1350
Adj. $R^2$	0.231	0.263	0.266	0.268	0.275	0.164
F-test	52.38	257.4	460.0	823.0	821.4	1188.7
Sample size	103	103	103	103	103	103

Note: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ . In parentheses are t-statistics based on robust standard errors with small sample. We use legal origins as the instrument for  $F_i$ . On the instruments for  $\beta_i$ , we use simulated patent protection (*siv\_ipr*), initial relative output ( $y_i - y_1$ ) and initial degree of openness. In column (2), (4) and (6) we add control regressors sec, gov, inf, open. Hansen's  $J$ -test stands for the test of overidentification of instruments, GMM  $C$ -test stands for testing the endogeneity of instrumented variables (orthogonality conditions). All regressions are estimated by GMM estimator. We use the command "ivregress gmm" in Stata to perform the regressions.

Table II: Convergence regression: 2SLS  
**Regression equation:**  $g_i - g_1 = \gamma_0 + \gamma_\beta \beta_i + \gamma_F F_i + \gamma_{\beta F} \beta_i \cdot F_i + \gamma_y \cdot (y_i - y_1) + \gamma_{\beta y} \cdot \beta_i \cdot (y_i - y_1) + \gamma_{Fy} \cdot F_i \cdot (y_i - y_1) + \gamma_x x_i + \varepsilon_i$ .

	1	2	3	4	5	6
	Private credit		Bank assets		Liquid liabilities	
Control regressors	Empty	Full	Empty	Full	Empty	Full
Coefficient estimates						
$\gamma_\beta$	0.0204*** (3.65)	0.0192*** (3.02)	0.0197*** (4.09)	0.0181*** (2.66)	0.0132*** (3.02)	0.0159** (2.40)
$\gamma_F$	0.0750** (2.24)	0.0736* (1.78)	0.0752** (2.14)	0.0687 (1.51)	0.0371 (1.16)	0.0682 (1.36)
$\gamma_{\beta F}$	-0.0210** (-2.49)	-0.0211** (-2.06)	-0.0201** (-2.38)	-0.0184* (-1.68)	-0.0102 (-1.26)	-0.0176 (-1.39)
$\gamma_y$	-0.0150** (-2.42)	-0.0136** (-2.13)	-0.0125** (-2.23)	-0.0105 (-1.65)	-0.00490 (-1.01)	-0.00584 (-1.08)
$\gamma_{\beta y}$	0.00699** (2.61)	0.00640** (2.42)	0.00568** (2.55)	0.00519** (2.09)	0.00431** (2.11)	0.00426* (1.82)
$\gamma_{Fy}$	-0.0234*** (-3.88)	-0.0221*** (-3.45)	-0.0203*** (-3.58)	-0.0195*** (-3.10)	-0.0225*** (-4.34)	-0.0186*** (-3.10)
$\chi^2$ -test for oid (p-value)	0.6407	0.5504	0.5465	0.3622	0.6198	0.5562
F-test for endog (p-value)	0.0000	0.0000	0.0000	0.0001	0.0003	0.0003
Adj. R <sup>2</sup>	0.233	0.254	0.276	0.294	0.289	0.216
F-test	17.75	13.70	22.49	11.86	27.09	17.57
Sample size	103	103	103	103	103	103

Note: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ . In parentheses are t-statistics based on robust standard errors with small sample. We use legal origins as the instrument for  $F_i$ . On the instruments for  $\beta_i$ , we use simulated patent protection (*siv\_ipr*), initial relative output ( $y_i - y_1$ ) and initial degree of openness. In column (2), (4) and (6) we add control regressors sec, gov, inf, open. The term “oid” stands for overidentification of instruments, “endog” represents the endogeneity of instrumented variables. All regressions are estimated by 2SLS estimator. We use the command “ivregress 2sls” in Stata to perform the regressions.

Table III: Relative-technology-level regression: GMM

**Regression equation:**  $\bar{y}_i - \bar{y}_1 = \zeta_0 + \zeta_\beta \beta_i + \zeta_F F_i + \zeta_{\beta F} \beta_i \cdot F_i + \zeta_y \cdot (y_i - y_1) + \zeta_x x_i + \nu_i$ .

	1	2	3	4	5	6
	Private credit		Bank assets		Liquid liabilities	
Control regressors	Empty	Full	Empty	Full	Empty	Full
Coefficient estimates						
$\zeta_\beta$	0.305*** (11.85)	0.330*** (7.78)	0.311*** (9.64)	0.372*** (9.42)	0.264*** (6.29)	0.311*** (4.46)
$\zeta_F$	2.754*** (10.92)	3.140*** (13.26)	2.383*** (7.32)	2.896*** (10.79)	1.625*** (4.19)	2.326*** (4.47)
$\zeta_{\beta F}$	-0.635*** (-10.21)	-0.748*** (-11.72)	-0.550*** (-7.10)	-0.687*** (-10.07)	-0.400*** (-3.96)	-0.578*** (-4.30)
$\zeta_y$	0.870*** (69.84)	0.898*** (30.16)	0.888*** (45.15)	0.896*** (32.17)	0.951*** (101.65)	0.958*** (46.23)
Hansen's $J$ -test (p-value)	0.4519	0.6317	0.3174	0.4820	0.2627	0.4212
GMM $C$ -test (p-value)	0.0227	0.1451	0.1177	0.2253	0.2015	0.2316
Adj. $R^2$	0.959	0.953	0.965	0.959	0.965	0.959
F-test	5243.7	1122.0	2193.5	982.3	3403.5	952.3
Sample size	103	103	103	103	103	103

Note: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ . In parentheses are t-statistics based on robust standard errors with small sample. We use legal origins as the instrument for  $F_i$ . On the instruments for  $\beta_i$ , we use simulated patent protection (*siv\_ipr*), initial relative output ( $y_i - y_1$ ) and initial degree of openness. In column (2), (4) and (6) we add control regressors sec, gov, inf, open. Hansen's  $J$ -test stands for the test of overidentification of instruments, GMM  $C$ -test stands for testing the endogeneity of instrumented variables (orthogonality conditions). All regressions are estimated by GMM estimator. We use the command "ivregress gmm" in Stata to perform the regressions.

Table IV: Relative-technology-level regression: 2SLS

**Regression equation:**  $\bar{y}_i - \bar{y}_1 = \zeta_0 + \zeta_\beta \beta_i + \zeta_F F_i + \zeta_{\beta F} \beta_i \cdot F_i + \zeta_y \cdot (y_i - y_1) + \zeta_x x_i + \nu_i$ .

	1	2	3	4	5	6
	Private credit		Bank assets		Liquid liabilities	
Control regressors	Empty	Full	Empty	Full	Empty	Full
Coefficient estimates						
$\zeta_\beta$	0.293*** (4.64)	0.306*** (4.47)	0.335*** (5.00)	0.339*** (4.86)	0.281*** (3.25)	0.314*** (3.70)
$\zeta_F$	2.591*** (5.74)	2.797*** (5.13)	2.510*** (5.79)	2.678*** (5.73)	1.729*** (3.36)	2.309*** (3.73)
$\zeta_{\beta F}$	-0.600*** (-5.07)	-0.678*** (-4.64)	-0.589*** (-5.34)	-0.639*** (-5.35)	-0.427*** (-3.09)	-0.577*** (-3.59)
$\zeta_y$	0.889*** (30.66)	0.889*** (25.54)	0.884*** (29.74)	0.891*** (25.80)	0.946*** (28.05)	0.938*** (27.67)
$\chi^2$ -test for oid (p-value)	0.4900	0.6450	0.3561	0.5504	0.3336	0.4245
F-test for endog (p-value)	0.0010	0.0036	0.0008	0.0008	0.0522	0.0151
Adj. R <sup>2</sup>	0.961	0.959	0.964	0.962	0.964	0.960
F-test	880.0	457.1	1125.7	571.0	902.9	507.2
Sample size	103	103	103	103	103	103

Note: \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ . In parentheses are t-statistics based on robust standard errors with small sample. We use legal origins as the instrument for  $F_i$ . On the instruments for  $\beta_i$ , we use simulated patent protection (*siv\_ipr*), initial relative output ( $y_i - y_1$ ) and initial degree of openness. In column (2), (4) and (6) we add control regressors sec, gov, inf, open. The term “oid” stands for overidentification of instruments, “endog” represents the endogeneity of instrumented variables. All regressions are estimated by 2SLS estimator. We use the command “ivregress 2sls” in Stata to perform the regressions.



Table V: Convergence club membership

1			2	
Countries most likely to converge			Countries uncertain to converge	
Cyprus	Ireland	Mali	United States	Mexico
Japan	Nicaragua	Peru	Germany	Philippines
Thailand	Guatemala	Togo	Austria	Rwanda
Switzerland	New Zealand	Ecuador	Netherlands	Botswana
Malaysia	India		Sweden	Central African Republic
China	Pakistan		France	Algeria
Jordan	Bangladesh		Israel	Congo Republic
Malta	Honduras		Australia	Sudan
Guyana	Iran		Korea	Italy
Luxembourg	Morocco		Norway	Iraq
Iceland	Brazil		Zambia	Tanzania
Singapore	Paraguay		Malawi	Argentina
Portugal	Costa Rica		Zimbabwe	Ghana
Papua New Guinea	Bolivia		Burundi	Jamaica
United Kingdom	Trinidad and Tobago		Benin	Sri Lanka*
Tunisia	Nepal		Niger	Uganda
Panama	Cote d'Ivoire		Cameroon	Haiti
Mozambique	Uruguay		Greece	El Salvador
South Africa	Swaziland		Syria	Belgium
Indonesia	Dominican Republic		Zaire	Sierra Leone
Canada	Venezuela		Denmark	Poland
Mauritius	Senegal		Finland	Bulgaria
Egypt	Colombia		Liberia	Hungary
Spain	Kenya		Gabon	Romania
Vietnam	Mauritania		Turkey	

Note: The estimated convergence parameters are based on the coefficients in regression 1 of Table II. The estimated convergence parameter increases within each group, as you move down each list and then to the right. There are three groups of classification: countries most likely to converge, countries uncertain to converge, and countries most likely to diverge in growth rate. A country is classified to the first group if its estimated convergence parameter is at least two standard deviation below zero, to the third group if its estimated convergence parameter is at least two standard deviation above zero, and to the second group otherwise. However, there is no country that belongs to the third group according to our estimates.

\* The estimated convergence parameter is negative (indicating convergence) in countries before Sri Lanka and positive (indicating divergence) in countries after (and including) Sri Lanka.